Discrete Diffusion Monte Carlo for Frequency-dependent Radiative-transfer Simulations

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DDMC is a technique for increasing the efficiency of Implicit Monte Carlo radiative-transfer simulations. We have recently developed an extension of DDMC for frequency-dependent radiative transfer. This new DDMC method is based on a frequency-integrated diffusion equation for frequencies below a specified threshold. Above this threshold we employ standard Monte Carlo. With an example test problem, we confirm the improved efficiency of our new DDMC technique.

Implicit Monte Carlo (IMC) is an accurate and robust method for modeling X-ray regime radiative transfer via Monte Carlo simulation in applications such as astrophysics and inertial confinement fusion [1]. Unfortunately, in optically thick regions the mean-free path between collisions is not only small, but collisions are also primarily scattering events. In this situation, the Monte Carlo transport process can be described as diffusive, particle histories consist of an excessive number of steps, and the resulting IMC calculation is computationally inefficient.

Discrete Diffusion Monte Carlo (DDMC) is a technique for increasing the efficiency of IMC in optically thick regions [2-4]. In DDMC, particles take discrete steps between spatial cells according to a spatially discretized diffusion equation. Because each discrete step replaces many smaller Monte Carlo steps, DDMC is more efficient than standard Monte Carlo. Furthermore, because DDMC is based on the diffusion approximation, which, due to the diffusive nature of IMC in optically thick regions, is valid in this regime, DDMC should yield accurate solutions as well. In practice, DDMC is combined with standard Monte Carlo to form a hybrid transport-diffusion method, where DDMC is used in optically thick regions and standard Monte Carlo is employed in optically thin regions.

We have recently developed an extension of DDMC for frequency-dependent radiative-transfer simulations. In these types of calculations, the opacity is typically a decreasing function of frequency such that a spatial region can appear optically thick for low frequencies but optically thin for high frequencies. Therefore, we base our new DDMC technique on a frequency-integrated diffusion equation for frequencies below a specified threshold and use standard Monte Carlo above this threshold. The frequency-integrated diffusion equation that we employ eliminates much of the scattering present in the standard Monte Carlo procedure, which is what leads to the inefficiency of IMC in optically thick regions.

To test our new DDMC method, we consider a sphere composed of a relatively transparent material with an embedded region composed of a relatively opaque material. However, the opacity of each material is such that the entire sphere is optically thick for low frequencies and optically thin for high frequencies. The sphere is initially in equilibrium at 1 eV and subject to an incident intensity that is described by a black body at 1 keV. We simulated this problem out to an elapsed time of 0.9 ns using three different schemes: (1) standard Monte Carlo only, (2) a hybrid method composed of both DDMC and standard Monte Carlo, and (3) Random Walk (RW), another technique for increasing the efficiency of IMC in optically thick regions, where particles take macrosteps over spheres according to an analytic diffusion solution [5]. The comparison between the hybrid method and RW is of particular importance as RW is the scheme most commonly employed to address the efficiency issues of IMC.

For this problem, the hybrid method was over 20 times faster than standard Monte Carlo alone, while RW was less than 10 percent faster. The material temperature at 0.9 ns produced by the hybrid method and standard Monte Carlo only calculations is plotted in Fig. 1. Here, as well, we see that the hybrid method based on DDMC yields an accurate solution.

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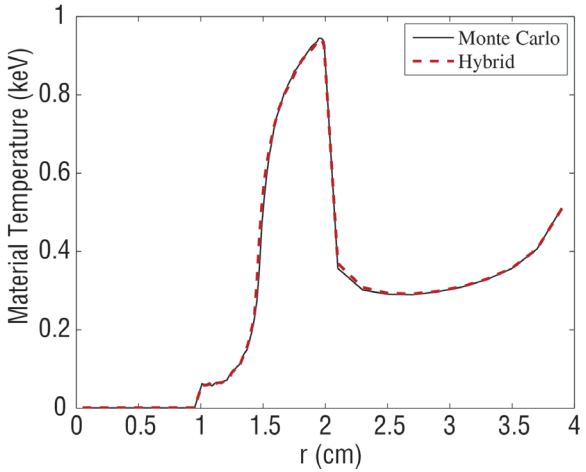

Fig. 1. Material temperature at 0.9 ns.

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Funding Acknowledgments
LANL Laboratory Directed Research and Development Program